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Research Article

Could bats be a good tool for monitoring highly fragmented and endangered forest habitats?

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Abstract

Habitat fragmentation poses a major threat to forest biodiversity, particularly in spatially restricted and endangered ecosystems. Identifying reliable indicators capable of reflecting fragmentation effects remains a key challenge for conservation-oriented forest monitoring. Bats are frequently proposed as bioindicators due to their sensitivity to habitat structure and prey availability; however, empirical evidence supporting their indicator value is often context-dependent and methodologically constrained. In this study, we evaluated the potential of bats as indicators of habitat fragmentation in the Eastern Mediterranean / Oriental Sweetgum (*Liquidambar orientalis*) forests, a highly threatened and naturally fragmented forest ecosystem with a very limited global distribution. Fieldwork was conducted in the Köyceğiz–Dalyan Specially Protected Area (southwestern Türkiye) between November 2022 and May 2023. Ten forest patches (30–250 ha) were classified into four categories based on patch size and fragmentation level. A total of 47 bat boxes were monitored biweekly, and bats using these boxes were captured, measured, and ringed to assess individual roost use across different fragmentation contexts. In total, 39 individuals belonging to four *Pipistrellus* species were recorded, all during the wintering period. Ringed individuals were unevenly distributed among fragmentation categories; however, statistical analysis (one-way ANOVA) did not detect a significant effect of fragmentation level on bat box selection. Although no clear fragmentation signal was detected, the limited monitoring duration, low recapture rates, and unbalanced sample sizes constrain statistical power. Consequently,

conclusions regarding the use of bats as indicators of forest fragmentation in this system should be regarded as preliminary and hypothesis-generating rather than definitive. Despite these limitations, this study represents the first ringing-based bat monitoring effort in Oriental Sweetgum forests and provides a critical baseline for future long-term, multi-method monitoring. Extended temporal datasets integrating ringing, acoustic monitoring, and fine-scale fragmentation metrics will be essential to clarify bat responses to fragmentation and to inform conservation strategies for this endangered forest ecosystem.
Keywords: Habitat fragmentation, bats, ringing-based monitoring, forest bioindicators, Oriental Sweetgum forests.

Introduction

Bats play a fundamental role in forest ecosystems through their contribution to insect population regulation, nutrient cycling, and ecosystem functioning (Vasko et al., 2020; Russo et al., 2023). As predominantly insectivorous mammals in temperate regions, bats are particularly sensitive to changes in habitat structure, forest continuity, and prey availability (Speakman & Thomas, 2003; Arlettaz et al., 2017; Burgin et al., 2018). Forest fragmentation resulting from land-use change and forestry practices has therefore been widely recognized as a major driver shaping bat activity patterns, roost selection, and species assemblages, making bats frequently proposed as indicators of forest integrity and ecological change (Bobrowiec et al., 2024; Apfelbeck et al., 2024; Russo & Jones, 2015).

A wide range of monitoring approaches has been applied to assess bat responses to habitat alteration, including acoustic surveys, roost inspections, telemetry, and capture-based methods such as mist-netting, bat ringing (banding) and harp trapping (Campbell et al., 1996; Scherrer et al., 2019; Russo et al., 2021). Among these approaches, bat ringing (banding) has a long-established history in Europe and has been extensively used as a reliable method for studying individual movement, site fidelity, population connectivity, and long-term demographic processes (Masing et al., 1999; Podlutsky et al., 2005; Pejic et al., 2018). Ringing-based studies have provided critical insights into both local habitat use and large-scale spatial dynamics, forming the basis for much of our current understanding of bat population ecology (Vasenkov et al., 2022).

In parallel, acoustic monitoring has become increasingly widespread due to advances in detector technology, non-invasive sampling, and the capacity to generate large datasets across broad spatial scales. Acoustic surveys are particularly effective for documenting bat activity levels, habitat use, and species presence, especially for aerial-hawking species (Frick, 2013). However, acoustic data

alone often provide limited information on individual-level processes such as site fidelity, demographic structure, or fine-scale habitat selection, and species identification can remain uncertain for taxa with overlapping echolocation call characteristics (Froidevaux et al., 2016; Frick, 2013). Consequently, ringing and acoustic monitoring are increasingly regarded as complementary rather than alternative methods, with their combined or context-dependent use offering a more comprehensive understanding of bat–habitat relationships (Russo & Jones, 2015).
Despite the long tradition and proven value of bat ringing, its application has been uneven across regions and habitat types. Many European ringing studies have focused on caves, hibernacula, maternity roosts, or relatively continuous forest systems, whereas highly fragmented forest landscapes remain comparatively understudied, particularly in the eastern Mediterranean region. This bias constrains our ability to generalize bat responses to fragmentation across different biogeographical contexts and forest types (Arlettaz et al., 2017).
The Eastern Mediterranean / Oriental Sweetgum (*Liquidambar orientalis*) forests represent a unique and highly threatened forest ecosystem characterized by a naturally restricted distribution, intensive human pressure, and pronounced habitat fragmentation (Ürker & Günlü, 2024). These forests are of high conservation concern due to their limited global range and the cumulative impacts of land conversion, hydrological alteration, and forest management practices (Ürker et al., 2023). Fragmentation within sweetgum forests results in a mosaic of small forest patches and edge-dominated habitats, conditions expected to strongly influence bat movement, foraging behavior, and habitat use (Ürker & Yorulmaz, 2020).
Although bats are frequently proposed as bioindicators of forest fragmentation, empirical evidence supporting their indicator value remains context-dependent and often inconclusive (Denzinger & Schnitzler, 2013). Many previous studies rely primarily on acoustic activity data, which may reflect short-term foraging responses rather than longer-term habitat suitability or population-level processes (Asbeck et al., 2020; Froidevaux et al., 2016; Frick, 2013). Ringing-based approaches, by contrast, provide individual-level information on site use and habitat association, yet have rarely been applied in eastern Mediterranean forest systems. Despite the extensive application of bat ringing across Europe, no ringing-based monitoring has previously been conducted in the Eastern Mediterranean / Oriental Sweetgum forests, which are both highly fragmented and of high conservation concern.

In this context, the present study aims to evaluate bat responses to forest fragmentation within sweetgum forests using ringing-based data. By focusing on individual capture records and site use across a fragmented forest landscape, this study seeks to contribute to a more nuanced understanding of bat–habitat relationships beyond activity-based metrics alone (Chen et al., 2023). Specifically, we assess whether fragmentation influences bat box selection patterns and explore the potential of bats as indicators of habitat fragmentation within this system. By addressing an understudied habitat type in a biogeographically distinct region, this study provides new insights into the applicability and limitations of ringing-based monitoring for evaluating fragmentation effects in Mediterranean forest ecosystems.

Material and methods

Study area

The study area selected for this research is the Köyceğiz-Dalyan Specially Protected Area (SPA), located in the southwest of Türkiye, within the boundaries of Muğla Province, encompassing Köyceğiz and Ortaca districts. It represents an officially designated protected area characterized by a mosaic structure of variously sized forest fragments. This area is of significant importance for the conservation of Eastern Mediterranean / Oriental / Anatolian Sweetgum Forests, especially as it hosts approximately 60% of this ecosystem globally (Özkil et al., 2017; Kavak & Wilson, 2018) (Fig. 1).

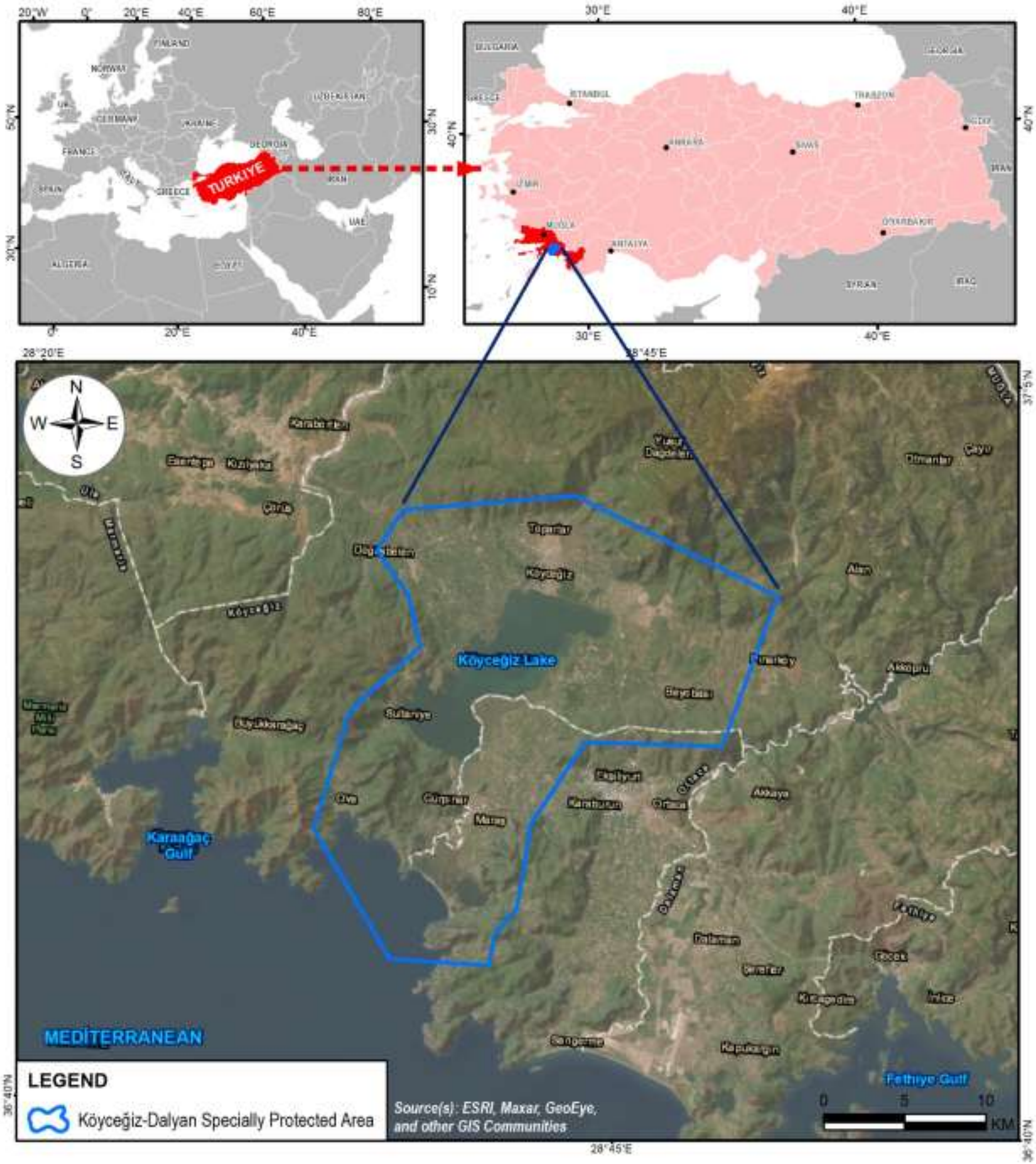

Figure 1. Location map of the study area.

The Köyceğiz-Dalyan SPA consists mainly of Calabrian pine and Anatolian (oriental) sweetgum forests, with herbaceous plants growing in marshes around Lake Köyceğiz (Akbaş & Varol, 2015). The Anatolian (Oriental) Sweetgum Tree (*Liquidambar orientalis* Miller), known colloquially as the "incense tree" in Türkiye, can reach an average height of 30-35 meters and a diameter of 100 cm, with a lifespan of 200-300 years. A resin known as sweetgum oil can be extracted from its trunk, (Arslan & Şahin, 2016). The Anatolian Sweetgum Tree is typically found in areas with mild winters (with an average temperature of 18°C), high rainfall (averaging 1000-1200 mm annually), high evaporation rates, low cloud cover, and high water tables (along rivers and streams, marshes, coastal areas, etc.) (Arslan & Şahin, 2016; Velioğlu et al., 2008).

The Anatolian Sweetgum Tree inhabits approximately 2000 hectares in southwestern Türkiye as well as a population of about 250 hectares on the island of Rhodes (Bozkurt et al., 2022). The extent of sweetgum forests decreased from 6,312 hectares to approximately 2,000 hectares between 1949 and 2014 (Ürker & Çobanoğlu, 2017). Toward the end of the 20th century, it was observed that about 60% of sweetgum forest coverage had been lost (Arslan & Şahin, 2016). Factors such as urbanization policies, unsuitable agricultural practices and reductions in groundwater levels pose threats to the survival of this species. The use of groundwater for citrus orchard irrigation and the planting of eucalyptus trees instead of sweetgum forests are among the factors contributing to the decrease in groundwater levels and the direct destruction of these forests (Akbaş & Varol, 2015). As a consequence of significant habitat fragmentation, the Anatolian Sweetgum Tree was listed as "Endangered (EN)" under the A2c criteria by the International Union for Conservation of Nature (IUCN) Red List of Threatened Species in 2018 (Kavak & Wilson, 2018). Studies began in July 2017 to determine the abundance and diversity of bats and their potential relationships with Anatolian Sweetgum Forests. Within the scope of those studies, 18 bat boxes were placed in 10 different sections of Anatolian Sweetgum Forests, ranging in size from 30 to 250 hectares, and 11 different bat species were identified through echolocation and direct observation studies (Ürker & Yorulmaz, 2020). In the aforementioned study, *Pipistrellus* sp., *Pipistrellus pipistrellus* (Common Pipistrelle), and *Hypsugo savii* (Savi's Pipistrelle) were identified through direct observations in bat boxes. Monitoring in the region continues with a total of 47 bat boxes, with preferences for two-roomed and single-roomed bat boxes (Figure-2).

Figure 2. Views of the two-roomed bat box (left) and single-roomed bat box (right) from the study area.

Study design

In this research, gloves, cloth bags, digital compasses, sensitive electronic scales with a precision of 0.1 g, and aluminum alloy bat rings were used as research materials. A total of 47 bat boxes/houses in the study area were regularly visited every two-weeks from 24 November 2022 to 28 May 2023. During regular field visits, bats found inside bat boxes were gently captured using gloves to avoid direct contact and placed in cloth bags. Each time bats were detected in the field, their weight and forearm lengths were measured and recorded alongside the individual's species and gender. After these measurements and observations, bats were ringed with the appropriate ring on their forearms, and the corresponding ring number was recorded. In bat boxes that were visited every two weeks, measurements were repeated for all previously ringed individuals, after which they were released back into the same bat box where they were found.

During fieldwork, rings with diameters of 2.4 mm, 2.9 mm, and 4.2 mm were available; however, since only species belonging to the *Pipistrellus* genus were identified in the field, only 2.4 mm rings were used. When placing the rings on a bat's forearm, care was taken to gently open their wings to a certain extent and slide the ring on delicately. Researchers took care not to disturb the bat while also ensuring that the ring remained securely attached by gently pressing and leaving a slight gap at the tips to prevent it from falling off. So, this noninvasive method does not necessitate approval from the Institutional Animal Care and Use Committee.

Throughout the fieldwork period, previously identified data were recorded in an Excel spreadsheet along with weather conditions. Upon the conclusion of fieldwork, data on re-observed individuals, box/house numbers, habitat preferences of ringed individuals, and gender-based preferences of boxes/houses were examined in further detail. All capture and ringing procedures were conducted under the approval obtained from the Research Permits Information System of the General Directorate of Nature Conservation and National Parks, and followed relevant animal welfare and handling guidelines.

Fragmentation analysis

A study conducted by Bozkurt et al. (2022) aimed to elucidate the characteristic habitat features of the existing Anatolian (Oriental) Sweetgum Forests in the region while considering isolation, fragmentation, area size, and the nature of the area (**Table 1**). According to Bozkurt et al. 2022, large patches (riparian forests) were defined as >100 ha, small patches (little groves) as 10–30 ha; fragmentation >40% was classified as 'fragmented', <10% as 'unfragmented', and between 10-40% as 'low fragmented'.

Table 1. Description of Habitat Characteristics (Bozkurt et al., 2022)

Habitat Characteristics	Description
ISOLATION	
Non-isolated	It has a connection to the sea, lake, or forest. Low disruption by settlements, agricultural areas, roads, etc.
Semi-isolated	It has a connection to the sea, lake, or forest. Moderate disruption by settlements, agricultural areas, roads, etc.
Isolated	It has no connection to the sea, lake, or forest. High disruption by settlements, agricultural areas, roads, etc.
FRAGMENTATION	
Unfragmented	Fragmentation rate 0-10%.
Low fragmentation	Fragmentation rate 10-40 %.
Largely Fragmented	Fragmentation rate 40-100%.
THE SIZE AND NATURE OF THE AREA	
Riparian forest	Areas larger than 100 hectares that are connected to a large body of water such as a lake or sea (presence of numerous permanent water sources).
Little Grove	Areas ranging from 10 to 30 hectares located in a bay or rural area (with or without a permanent water source.)

In this study, 10 different sections of the Anatolian Sweetgum Forest within the Köyceğiz-Dalyan SPA, ranging in size from 30 hectares to 250 hectares, were selected as the study area. These forest sections, classified into four categories based on their fragmentation status, currently host a total of 47 bat boxes (Table 2; Fig. 3).

Table 2. General characteristics of the surveyed habitat patches.

No	Locations	Habitat Characteristics	Area (ha)	Bat Boxes/Houses*
1	Yangı (Karabatak)	Non-isolated, Unfragmented, Riparian forest (Unfragmented Large)	>200	SG17, SG18, **SG19**, **SG20,** SG21, **SG22,** SG23, SG24, SG25
2	Toparlar	Semi-isolated, Largely fragmented, Riparian forest (Fragmented Large)	>200	**SG26, SG27,** SG28, SG29 **SG30,** SG31, SG32, SG33, SG34, SG35
3	Okçular	Isolated, Low fragmentation, Little grove (Fragmented Small)	10-30	SG1, SG2, SG3, SG4
4	Sultaniye	Non-isolated, Unfragmented, Little grove (Unfragmented Small)	10-30	SG45, SG46, **SG47**
5	Kersele	Non-isolated, Unfragmented, Little grove (Unfragmented Small)	10-30	SG40, SG41, SG42, **SG43,** SG44
6	Tepearası	Semi-isolated, Largely fragmented, Riparian forest (Fragmented Large)	>100	SG5, **SG6,** SG7, SG8, SG9
7	Kavakarası	Semi-isolated, Largely fragmented, Riparian forest (Fragmented Large)	>100	SG10, **SG11,** SG12, SG13, SG14
8	Eski Köyceğiz	Semi-isolated, Low fragmentation, Little grove (Fragmented Small)	10-30	**SG15**
9	Zeytinalanı	Semi-isolated, Low Fragmentation, Little grove (Fragmented Small)	10-30	SG16
10	Hamitköy	Isolated, Unfragmented, Little grove (Unfragmented Small)	10-30	SG36, SG37**, SG38,** SG39

* Ringing studies were carried out in bat boxes/houses written in bold font.

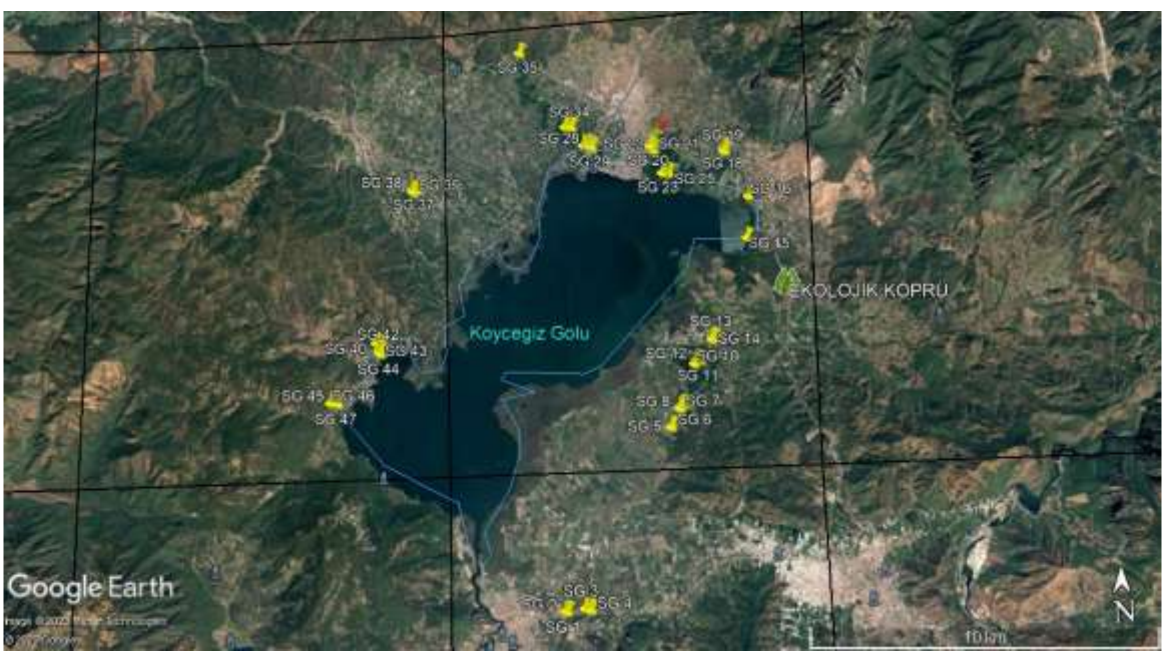

Figure 3. Distribution of bat boxes across the study area.

During statistical analysis, the 10 different sections of the study area were categorized into four distinct classifications based on fragmentation (unfragmented large, unfragmented small, fragmented large, fragmented small) **(Table 2).** We treated the number of ringed bat individuals per fragmentation/size category as the response variable and the four fragmentation classes as the predictor. Within the presence-absence hypothesis framework, the following hypotheses regarding the study data were examined and analyzed by using one-way analysis of variance (ANOVA):

H_0: There is no relationship between habitat fragmentation and bat individuals' roost selection.

H_1: There is a relationship between habitat fragmentation and bat individuals' roost selection.

Given the small and unbalanced sample sizes, results should be interpreted as exploratory. A Fisher's exact test or a generalized linear model with count data (e.g. Poisson/negative binomial) may be more appropriate in future studies."

Results

The bat ringing study, which started on November 24th, 2022, continued regularly one day every two weeks until May 28th, 2023. During fieldwork, roosting activity was observed in 12 out of 47 bat boxes examined. A total of 39 bat individuals belonging to 4 species of the *Pipistrellus* genus were ringed during the study. The ringed individuals were identified by species, and their forearm lengths, weights, and genders were recorded. Only 2 individuals were observed a second time, and 2 individuals were observed 3 times during the study; their measurements were repeated. In total, 14 males and 25 females were ringed. Throughout the study period, 27 individuals of the species *Pipistrellus pipistrellus*, 8 individuals of the species *Pipistrellus kuhlii*, 3 individuals of the species *Pipistrellus nathusii*, and 1 individual of the species *Pipistrellus pygmaeus* were ringed **(Table 3).**

Table 3. Details of Bat Box Usage Based on Number of Individuals.

DATE OF RINGING & OBSERVATION	BOX NO	INDIVIDUALS	GENDER		SPECIES			
			F	M	*Pipistrellus pipistrellus*	*Pipistrellus kuhlii*	*Pipistrellus nathusii*	*Pipistrellus pygmaeus*
24.11.2022	SG27	4	3	1	4	-	-	-
	SG38	1	1	-	1	-	-	-
25.11.2022	SG11	1	-	1	1	-	-	-
08.01.2023	SG6	3	3	-	1	2	-	-
	SG15	1	1	-	-	-	1	-
	SG47	1	-	1	-	1	-	-
	SG38	3	1	2	1	-	2	-
31.01.2023	SG6	2	2	-	1	1	-	-
	SG22	2	1	1	2	-	-	-
	SG15	1	1	-	-	-	1	-
	SG38	1	1	-	-	1	-	-
	SG26	1	-	1	1	-	-	-

28.02.2023	SG6	4	4	-	3	1	-	-
	SG38	2	1	1	-	2	-	-
	SG27	2	1	1	2	-	-	-
	SG30	1	-	1	1	-	-	-
	SG15	1	1	-	-	-	1	-
01.03.2023	SG20	5	4	1	5	-	-	-
	SG22	5	4	1	5	-	-	-
27.03.2023	SG38	1	-	1	1	-	-	-
	SG19	1	-	1	1	-	-	-
01.05.2023	SG43	1	1	-	-	1	-	-
	SG27	1	-	1	-	-	-	1

Among the 39 ringed individuals, 6 were ringed for the first time in November 2022, 13 in January 2023, 6 in February 2023, 12 in March 2023, and 2 in May 2023. After May 2023, the box checks were conducted monthly during the summer period, but as observed over the previous 5 years, no roosting activity was observed in any of the boxes (Ürker & Yorulmaz, 2020). Throughout the duration of the study, including the ringed species described above a total of 12 different bat species and 2 genera have been recorded in the Oriental Sweetgum Forests through various detection methods since 2017 (Table 4).

Table 4. Current Bat Fauna of Anatolian Sweetgum Forests (Developed from Ürker & Yorulmaz, 2020)

SCIENTIFIC NAME	ENGLISH NAME	BERN	CITES	IUCN RED LIST Ver.2025.2	RECORD TYPE
Rhinolophus ferrumequinum	Greater Horseshoe Bat	EK-II	-	LC	Empirical Observation
Myotis daubentonii	Daubenton’s Bat	EK-II	-	LC	Empirical Observation
Myotis emarginatus	Geoffroy's Bat	EK-II	-	LC	Active Detector
Pipistrellus pipistrellus	Common Pipistrelle	EK-III	-	LC	Full-Spectrum Detector, Active Detector, Empirical Observation, Bat Box, Ringing
Pipistrellus pygmaeus	Soprano Pipistrelle	EK-II	-	LC	Full-Spectrum Detector, Empirical Observation, Ringing
Pipistrellus kuhlii	Kuhl's Pipistrelle	EK-II	-	LC	Full-Spectrum Detector, Empirical Observation, Ringing
Pipistrellus nathusii	Nathusius's Pipistrelle	EK-II	-	LC	Full-Spectrum Detector, Ringing
Hypsugo savii	Savi's Pipistrelle	EK-II	-	LC	Full-Spectrum Detector, Bat Box
Plecotus macrobullaris	Alpine Long-eared Bat	EK-II	-	LC	Empirical Observation
Miniopterus schreibersii	Schreiber's Bent-winged Bat	EK-II	-	VU	Full-Spectrum Detector
Myotis sp.	Mouse-eared bats	-	-	-	Full-Spectrum Detector
Nyctalus sp.	Noctule bats	-	-	-	Full-Spectrum Detector

A total of 39 individuals from 4 different species of the *Pipistrellus* genus were observed and ringed during the research period. Of these, 15 individuals were ringed in the large forest and highly fragmented patches, 10 in the small forest and highly fragmented patches, 14 in the large forest and sparsely fragmented patches, and none in the small forest and sparsely fragmented patches. For the statistical analysis, For analysis, we grouped the ten patches into four categories as seen in Table 2: unfragmented large, unfragmented small, fragmented large, and fragmented small, based on Bozkurt et al. (2022) and our area thresholds. Using the presence-absence hypothesis, the relationship between habitat fragmentation and the selection of roosting boxes by ringed bat individuals was investigated. While the dependent variable in this study was ringed bat individuals, the independent variable was habitat fragmentation. In this context, hypothesis testing was conducted through one-way analysis of variance (ANOVA) in SPSS (Version 26). The analysis did not detect a statistically significant effect of fragmentation ($p > 0.05$), but low sample sizes and unbalanced groups limit the power of this test (Table 5).

Table 5. Homogeneity Test and ANOVA Test Results.

Descriptives

Number of individuals ringed

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
1,00	9	1.5556	2.60342	0.86781	-0.4456	3.5567	0.00	7.00
2,00	20	0.7500	1.88833	0.44224	-0.1338	1.6338	0.00	7.00
3,00	14	0.7143	1.85757	0.49646	-0.3582	1.7868	0.00	7.00
4,00	4	0.0000	0.00000	0.00000	-0.0000	0.0000	0.00	0.00
Total	47	0.8298	1.94846	0.28421	-0.2577	1.4019	0.00	7.00

Test of Homogeneity of Variances

		Levene Statistic	df1	df2	Sig.
Number of individuals ringed	Based on Mean	1.885	3	43	0.146
	Based on Median	0.671	3	43	0.575
	Based on Median and with adjusted df	0.671	3	36.436	0.575
	Based on trimmed mean	1.415	3	43	0.252

ANOVA

Number of individuals ringed

	Sum of squares	df	Mean Square	F	Sig.
Between Groups	7.809	3	2.603	0,671	0.575
Within Groups	166.829	43	3.880		
Total	174.638	46			

Discussion

Bats are important mammalian bioindicators (Hill & Smith, 1984; Vaughan et al., 2000; Scherrer et al., 2019; Russo et al., 2021); due to their hibernation, limited breeding, and mating periods, they are more sensitive to anthropogenic and environmental changes that may occur in forests (Yorulmaz et al., 2018; Hendel et al., 2023). Presently, the poor ecological understanding of the roosting and foraging needs of forest bats poses a significant challenge in forest management (Taylor, 2006; Silvis et al., 2016); hence, establishing the bat-forest relationship in an area where biodiversity is sustainable will facilitate improved management strategies (Schroder & Ward, 2022). In this study of the roosting behavior of bats in patches of Anatolian Sweetgum Forests, species-wise examination of simultaneous use of bat boxes revealed that different species (*Pipistrellus pipistrellus, Pipistrellus kuhlii, and Pipistrellus nathusii*) were roosting together. Bat roosting activity was found to be most intense in January and March 2023. When bat monitoring data from the previous 5 years were included, it can be said that bats prefer these forests as active roosting habitats during the hibernation period. However, no roosting behavior was observed in these forests during the extremely hot and dry period between late May and mid-October 2023. Instead, it was confirmed that feeding behavior increased during this period. During the summer period, bats are assumed to migrate to Austrian pine forests (*Pinus nigra* forests) at higher elevations, which are relatively cooler and less humid (Dodds & Bilston, 2013). Although this study was explicitly designed to test the potential of bats as indicators of forest habitat fragmentation, no statistically significant effect of fragmentation on bat box selection was detected. Consequently, any conclusions regarding the indicator value of bats in these highly fragmented forest systems should be considered preliminary and interpreted with caution, particularly given the short monitoring period and limited sample size.

Bat monitoring studies using ringing methods have been conducted worldwide to observe species-specific activities of bat populations (Norman et al., 1999). This ringing study is the first of its kind in Türkiye and the wider Eastern Mediterranean Basin at the national and regional levels. The study aims to serve as a baseline for future, longer-term monitoring studies. A literature review reveals that monitoring studies can support research by identifying population sizes, species-specific migration distances, reasons for using different habitats, etc. (Vlashenko, 2012). Furthermore, the presence of suitable habitats for bats is directly related to the structure of the forest (Newman et al., 2021; Kristin, 2005; Hendel et al., 2023).

Although special efforts are required for the recapture of ringed individuals (Masing et al., 1999), it was not surprising that four individuals were recaptured during just a 6-month monitoring period. The data obtained from a short-term study in a region where bat boxes are preferred can be considered as an indication that significant data will be obtained about bat habitat preferences during long-term monitoring periods in this study area. “Absence of Evidence” does not mean “Evidence of Absence”. Therefore, further field analysis using different and robust methods is necessary in the future. A 19-year study conducted near the "Grotta Marelli" cave in Campo de Fiori Regional Park (Varese, Northern Italy) revealed a significant male dominance in that population, with only 2 female individuals identified of the 42 bats captured (Bologna et al., 2018). In contrast, this research identified female dominance with only 14 male individuals ringed compared to 25 females.

Evaluation of habitat fragmentation characteristics in areas with occupied bat boxes revealed that individuals did not roost in fragmented small forest patches at all, with 15 individuals roosted fragmented large forests, 14 individuals roosting in unfragmented large forests, and 10 individuals roosted fragmented small forests. However, statistical analysis did not revealed an effect of habitat fragmentation on bat box selection. These findings are paralleled by others, as a study conducted on the two most common bat species in Europe, *Pipistrellus pygmaeus* and *Pipistrellus pipistrellus*, found that *P. pipistrellus* individuals had very general feeding area preferences and did not make specific selections (Watts et al., 2006). In this study, however, while 27 individuals of *P. pipistrellus* were ringed, only 1 individual of *P. pygmaeus* was ringed. Previous findings that *P. pipistrellus* individuals are not typically forest-dependent and make habitat-independent choices about food and roosting suggest selections independent from habitat fragmentation characteristics.

The prioritization of land for meeting human needs can reduce the sustainability of ecosystems, particularly in terms of crop production (Foley et al., 2005), and anthropogenic habitat loss is considered as a primary environmental issue (Riva et al., 2024). A monitoring study conducted over 35 years on five different continents revealed that habitat fragmentation reduced biodiversity by 13-75%, causing a decrease in biomass and differentiating all ecosystem functions, including nutrient cycles (Haddad et al., 2015). Especially in China, when the effects of multiple habitat fragmentation on habitat quality were examined, it was determined that the parameters that most negatively affected habitat quality were increases in habitat isolation and decreases in habitat area (Xu et al., 2017). In this study, researchers emphasized three important points that can minimize

negative effects and reduce losses due to habitat fragmentation: (1) Sharp delineation of agricultural areas, urban, and ecological areas by the state; (2) Developing strategies for protected areas, with national parks being the focal point, to ensure the protection of ecosystems as a whole; and (3) Developing sustainable practices that will enable fragmented or isolated areas to interact with the ecosystem as a whole through ecological networks (Xu et al., 2017).
Establishing the causality between habitat loss and fragmentation is important to reveal their effects on biodiversity (Miller et al., 2003; Butti et al., 2022). Although habitat fragmentation and habitat loss are often considered together by many researchers (Russo et al., 2021; Li et al., 2021), findings obtained from these studies can often be misleading (Neubaum & Aagaard, 2022). The effect of habitat fragmentation should be examined independently of habitat loss in order to accurately measure its specific effect on biodiversity (Riva & Fahrig, 2023; Rowley et al., 2024).

Conclusion

In this study, bat ringing methodology was used for the first time in Türkiye at the scale of the Eastern Mediterranean Basin. It is expected that the increasing use of bat ringing in the Eastern Mediterranean Basin will significantly contribute to the collective understanding of cause-and-effect relationships in bat ecology, unlike other methods that solely detect the presence of bats. Thus, in addition to identifying some ecological preferences of bats, this research will improve planning strategies that aim to minimize the adverse effects of climate change or human-induced impacts on bat populations, not only for Türkiye but also for the entire Eastern Mediterranean Basin. While our study did not detect a significant effect of fragmentation on box selection, this may reflect limited statistical power rather than the true absence of an effect. The lack of monitoring data for the Eastern Mediterranean Basin constitutes one of the major deficiencies for decision-makers and managers working on nature conservation and forestry management to develop and manage a healthy biodiversity plan in the coming years. This study also serves to strengthen sustainable forestry management that accounts for wildlife and biodiversity elements by providing data that can be integrated into management plans carried out by Forest Services in different forest ecosystems across countries. This study tested whether forest habitat fragmentation has an effect on bat box selection in terms of bat roosting behavior, and data analysis obtained from the ringed individuals concluded that there was no such effect. However, it is necessary to examine all the details of the study in the context of previous work; for example, this study demonstrated that bats actively use not only cave ecosystems but also forest ecosystems. This evaluation of bat-forest ecological relationships will particularly contribute to forest and nature conservation units, clarifying habitat and even species-specific conservation methods. This ringing study covers a period of 6 months, in comparison to long-term monitoring studies covering decades that are conducted globally.

Despite the short duration, this study supplements 5 years of regular bat monitoring data from the same research team in this study area conducted previously. Therefore, it can be concluded that these results are acceptable within their scope of the research. The descriptions of the ringed individuals, including their box preferences and usage times, especially in the study area, provide a basis for future monitoring studies. Studies that continue this research by increasing the number of observations and observers, placing more bat boxes in research stations, and/or trying different bat boxes will continue to contribute to monitoring studies. In addition, continued maintenance and repair of bat boxes to prevent their use by different groups of organisms may increase the utilization of bat boxes. Future work should extend ringing to multiple years and integrate continuous fragmentation metrics (e.g. edge density, connectivity indices) with long-term acoustic and capture data.

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